PLENARY SPEECH
KEYNOTE SPEECHES
LIST OF ATTENDEES
OF
SECOND SYMPOSIUM ON

# THE INTERACTION OF NON-NUCLEAR MUNITIONS WITH STRUCTURES

PANAMA CITY BEACH, FLORIDA

APRIL 15-18, 1985

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This document represents the pienary speech, keynote speeches and list of attendees of the Second Symposium on The Interaction of Non-Nuclear Munitions with Structures, Panama City Beach, Florida, April 15-18, 1985. The symposium was sponsored by the following U.S. Air Force agencies:

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All the manuscripts in this document have been approved for public release either by the author or the cognizant federal agency.

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# PLENARY ADDRESS

George E. Ellis

It is a pleasure for me to welcome you--both to the beautiful and warm Gulf Coast of Florida and to this important gathering. I want to thank you for making time in your busy schedules to attend this symposium on the Interaction of Non-Nuclear Munitions with Structures. Some of you are visitors from outside the United States...a special welcome. Your participation will enhance the value of the symposium; we especially appreciate your presence.

As most of you know, this is the Second Air Force-Sponsored Symposium on the Interaction of Non-Nuclear Munitions with Structures; the first was held at the US Air Force Academy about two years ago.

The purpose of this symposium is much the same as that of the first. We want to provide a forum for an open exchange of information and ideas. We want to create the opportunity to learn about the many ongoing research and development efforts and accomplishments. Most importantly, we want to extend technology for the mutual benefit of all participants. A free exchange of technological ideas will benefit the collective security and welfare of all of our nations. New ideas can also enhance the capabilities of our defense forces.

My interest in and support for this symposium are kindled by the fact that through my boss Maj. Gen. Duke Wright, our Engineering and Services Forces are responsible for developing the civil engineering technology and support structure that will ensure the readiness and survivability of the US Air Force in a wartime environment.

Almost every nation faces some serious threat from external or internal adversaries. It is unfortunate that we live in an unstable world. It is an unfortunate fact. Most likely the world will continue to remain dangerously unstable.

We in the military profession are sworn to preserve the security of our country. How do we achieve this goal? We access the threat, and then organize, equip, and train sufficient forces to counter that threat. We prepare our troops for a fight that we pray will never occur.

In terms of an international threat, our primary concern, as you well know, is the Soviet Union, which has steadily grown militarily over the past 20 years. Soviet military doctrine has also evolved over those 20 years to match their growth. A quote from a 1984 U.S. government publication, <u>SOVIET MILITARY POWER</u>, has relevance. Quote: Changes in the nuclear balance over the past 25 years have led to periodic modifications in Soviet doctrine--in step with major growth of Soviet nuclear capabilities. In the early 1960s, the Soviet Union envisioned war with the west to be nuclear from the outset; a decade later, doctrine was modified to allow for a conventional phase in a NATO-Warsaw Pact confrontation; and it now appears that the Soviets may theorize that such a major war could remain non-nuclear; close quote.

Even in terms of an actual nuclear conflict, Soviet doctrine calls for a continuing conventional arms offensive during and after any nuclear phase. The priority targets will be nuclear weapons, nuclear delivery systems; command, control, and communications; air bases; and political administrative centers. Therefore, I would argue that across the entire spectrum of international conflict, the interaction of non-nuclear munitions with structures is a contemporary and important subject.

There is another less obvious, but ominous, reason why the issues of this symposium are so important. Within the past few years, a new international menace has surfaced: I'm talking about international terrorism. Terrorist attacks using conventional munitions have in-

creased almost exponentially over the past 10 years. I know that many of the ideas and technologies discussed here can be applied to mitigating the damage associated with these attacks and can blunt this miserable threat.

We in the free world must keep pace with mitigating these threats by continuing and expanding our research and development. We need to improve procedures, materials, and equipment. The Air Force is one of the key contributors to our national security and one of the prime users of the materials and equipment the research and development community develops.

The Air Force provides four types of forces: (1) strategic aircraft and missile forces, (2) land-based tactical air forces, (3) aerospace defense forces, and (4) airlift forces. The mission of the Air Force--simply stated--is to fly and fight and win. Unlike the other armed services, we accomplish our fly and fight mission from air bases that are fixed platforms.

Our primary job as Air Force engineers is to provide and maintain the fixed platforms from which we fly and fight. That job also includes all the support infrastructure that is necessary to generate flying operations from those platforms.

The platform means airfield facilities to launch, recover, and service aircraft; we call it sortie generation. The platform is runways, taxiways, aprons, lighting, navigational aids, and so on.

The support infrastructure that supports operation of the platform includes many types of facilities. Examples include those required to protect and maintain aircraft--hardened shelters, avionics shops, liquid oxygen plants, etc. Other examples are secure facilities in which our people can live and work, command posts, communication centers, and sleeping quarters. We must also develop survivable utility systems, including electrical generation and distribution, water, waste, and fuel. The solution is further complicated because we will fight in a chemical as well as a non-nuclear environment.

Accomplishing this engineering mission would be relatively simple, even in wartime, if we were not subject to attack. In past wars we in the United States Air Force have suffered little damage to our air bases due to enemy attack. But in the next major conflict, should it ever occur, our air bases would almost certainly be subjected to attacks that would result in significant infrastructure damage. Thus we need to improve our concepts, materials, and equipment to quickly repair this damage.

My real concern is that we have more questions than answers--more problems than solutions. And the kinds of answers and solutions we need aren't always available off the shelf. Often-times they can only be obtained through intense research and development.

Research and development is an integral part of the Air Force and has been throughout its history. The Air Force is itself an outgrowth of the technological evolution affecting modern warfare. General H. H. (Hap) Arnold, as early as the fall of 1944, created the Army Air Force's Scientific Advisory Group, chaired by the eminent aerospace pioneer Dr. Theodore von Karman. Known now as the Air Force Scientific Advisory Board (SAB), its purpose is to advise the Air Force leadership on the future directions of science and technology as it affects the doctrine and application of air power.

Extracting from an article by Maj. Gen. Wright published in THE MILITARY ENGINEER, the Air Force Scientific Advisory Board recently concluded a special study which considers, among other important issues, the air base as a critical element to the success of our warfighting capabilities. To address the SAB's recommendations, we have expanded the Air Force Engineering and Services research and development programs. We need an expanded research and development technology base.

Our Air Force civil engineering community, made up of the sponsors of this symposium, has responded well in achieving high levels of protection for our people, for our aircraft, and for our equipment. We are working on revolutionary new concepts which will enable us to rapidly recover our bases after enemy attack. But we can do better. We are developing procedures and heavy equipment that will increase the productivity of our people in a wartime environment. Our success to date has been through a unique consortium of researchers representing colleges and universities, the corporate sector, other federal research agencies, our sister services, and the laboratory structure of the Air Force.

Our research and development efforts have been directed toward developing public confidence in the Air Force as an institution. We have a responsible concern for facing and solving environmental problems while sharing the results of our research with the worldwide community. On the one hand, we are dealing with the

nation's survival in a world threatened by foreign aggression. On the other, we are dealing with the survival of the delicate environmental systems around our bases, around the world, and even, to an increasing degree, outer space.

The Air Force that will enter the 21st century is largely in place today. During the next 15 years, the base support infrastructure on which the Air Force depends will probably not undergo drastic change. Therefore, it is important that each new weapon system recognize the unchanging character of supporting facilities. This will require the coordinated effort of those who shape operational doctrine and strategy and those who formulate our research and development programs to ultimately make it possible for the Air Force to fulfill successfully its future mission.

The Air Force of today and tomorrow, like that of the past, is a unique structure forged from science, engineering, innovation, and the talented, motivated people who bring it all together. The goal is to ensure the strength to deter war if we can; the power to win if we must fight.

It is somewhat ironic that the rapid advancement of science and technology which has led to high tech hardware development--space systems, computers, complex weapon systems, and new materials--has created an urgent need for similar advances in support technology. Certain fundamental vulnerabilities become even more critical as the base support infrastructure is made more sophisticated and complex.

We need better pavement systems--ones that can withstand attack or can be quickly and easily fixed after attack. We've built our third generation of aircraft shelters, but there are still improvements that can be made in shelter design. We also need state-of-the-art survivable facilities for our people and critical mission components. We need to take a hard look at our utility systems in terms of survivability and repairability. To keep pace, research and development and technical exchange at symposia like this makes a lot of good sense. None of us singularly have the people, time, money, and facilities to accomplish everything that needs to be done. We must exchange ideas and benefit from the synergistic effect of quality cooperation.

This symposium was organized to encourage your involvement in our programs. I challenge each of you to take maximum advantage of the opportunity. Synthesize new ideas from past accomplishments. Generate advanced avenues for exploration, for basic research, and for applied research. We need to translate today's technology--today's understanding--into new systems for use in the field, and we need to start now. By technical exchange, we can achieve more than the sum of the individual parts, and together we can achieve a greater security for our nations. The keys are understanding and exchange. Let us strive for these and together we can shape a safe and free future. Thank you.

# DECADE - PLUS TWO

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Two years ago, at the First Symposium on The Interaction of Non-Nuclear Munitions with Structures, Allen Ross was kind enough to invite me to deliver one of the keynote speeches and, on that occasion, I chose as my title, "Has a Decade Made a Difference?" My thesis at that time was that, at least for the previous decade, inadequate systemmatic attention had been given to the study of the effects of non-nuclear weapons on structures and, conversely, to the design of structures to resist the effects of such weapons. I may have overstated the point somewhat, because a very substantial amount of very useful work had been done during that period. But, by and large, I think that the observation was generally valid. I concluded my remarks that morning with the following statement, which was made in reference to the program of the symposium then being convened.

> ".....It is, indeed, a comprehensive program that embraces the full spectrum of problems that confront us. It represents impressively the recently reawakened interest in protective construction to resist the effects of conventional weapons and it brings to bear on these problems the technologies of a multiplicity of disciplines. It does, indeed, provide a strong springboard for the further development of protective construction technology. Let us hope that the impetus provided by this symposium will not be lost, but that the work here begun will be continued. We can ill-afford another decade of relative inactivity in this very important aspect of our nation's military preparedness."

Well, it would appear that the impetus given by that first symposium two years ago has most certainly not been lost. We have but to look at the program of the symposium now being opened to observe that the interested community has not been idle during the last two years. This year's program contains some 80 papers (exclusive of keynoters and other stage-setting presentations) which were produced by 143 authors from 54 organizations. By comparison, the program of the 1983 symposium contained 66 papers authored by 117 investigators representing 38 organizations. It is interesting to note not only the substantial increases in the numbers of papers, people, and organizations that are represented in this current program, but also, and perhaps more importantly, that only 41 authors from 22 different organizations are repeat performers.

It is abundantly clear, therefore, that there is a very large community that is actively involved in the study of problems being addressed by this symposium. It is equally clear that a forum, such as that which is being provided here, is sorely needed so that the investigators involved in these numerous studies can conveniently exchange their views and debate their differences.

Having confirmed convincingly the legitimacy of this symposium, I needed, then, only to confirm the legitimacy of my appearance on its program. Dr. Ross invited me to make one of the keynote speeches at the opening session today. Webster defines a "keynote speech" as "an address or speech that presents the essential issues of the assembly." And that didn't sound like too difficult a task. Obviously, the essential issue, or objective, of this assembly is to report on the present status of our understanding of the way structures respond to the forces and motions imposed upon them by the impact and/or the explosion of non-nuclear munitions.

And that is precisely what this symposium is going to do. A quick glance at its program will confirm that to be the case. There are large numbers of papers that speak to all aspects of the general question that is before us. There are papers on the characteristics of the blasts that are produced by the explosion of conventional weapons; and there are papers dealing with the impact on and penetration of structures by such weapons. There are papers on the measurement of the free-field effects of the explosion of such weapons in soil; and there are papers on the response of structures to these effects, on the properties of the materials of which the structures are made, and on the design of structures to resist the effects that might be imposed upon them by these weapons. Indeed, all aspects of the question that is embodied in the

symposium title are represented on this program. And you don't need me to stand up here and reac the program to you to identify these essential issues.

But perhaps I might be helpful if I can promote some critical introspection among us by asking some questions, not about these "essential issues" that we study, but rather about how we study them. If these questions sound critical, please understand that they are not intended to be critical of any particular individuals or organizations, but rather of the collective "us". And I include myself in that "us" because, on more than one occasion, I have been a party to the kinds of the things about which I am now going to complain.

Do we design our experiments as carefully as we should? Do we measure those things that we should measure, or simply those things that we can measure? Should we not place greater emphasis than we sometimes do on the design of the instrumentation to be used in an experiment so as to produce data that will lend itself more readily to comprehensive analysis?

To illustrate the point, let me indulge in a pet peeve. For more years that I care to remember, I have been involved in the planning and interpretation of experiments which had as their immediate primary objectives the study of the responses of an assortment of structures to blast-induced loads, the ultimate objectives of those tests having been the development of analytical methods that would predict reliably the observed behavior of the structures under study.

But almost without exception, reliable internal time-dependent strain data and/or external time-dependent deformation data, which are essential to the confirmation of analytical methods, were not available, at least not to the extent that was needed. To be sure, we almost always had an abundance on strain gages installed on the structure, but almost always we also wound up with a large number of strain records whose validities were highly questionable after only a few milliseconds of response. And such records are simply not enough to permit us, computationally, to reproduce the responses of structures in the domains of very large inelastic deformation.

Additionally, with a few exceptions, we have not been able to measure successfully the gross response of the structure, as a function of time. Far more frequently, we know that, at the instant that the blast wave hits the structure, its deflection is zero and that, when the dust settles, the structure has collapsed or still exists, having suffered a total deflection of x-inches. To be sure, this is useful information, but reliable time histories of both the internal strains and the external deformations would be infinitely better.

Just recently, I had occasion to try to check computationally the response of some shallow-buried reinforced concrete box-type structures to some simulated nuclear weapon explosions. And I checked the final deflections of those structures pretty well--really, somewhat better than I had expected to be able to check them--except in one respect. While I computed the magnitudes of the maximum observed deflections within acceptable limits in all cases, in the two cases in which time-dependent response data were available, the times at which I computed those maximum deflections to have occurred differed from the test data by a factor of almost two.

Whether these differences were the fault of my calculations or of the measured results is uncertain. But if there had been more reliable time-dependent response data available, I could answer that question. And until such data become available, I must always use that analytical methodology hesitantly; is it or is it not an acceptable predictor of the response of other reinforced concrete structures to other blast-induced loads?

Don't get me wrong. The test series to which I refer was an excellent one, which yielded some very useful information. But I wonder if the objectives of that test series might not have been even better served if we had spent more time and effort on the development of reliable time-dependent response measurement techniques that could have been used in it.

Another question that has bothered me over the years is this. How do we know when we have studied a problem enough? We can never fully understand the very complex physical systems with which we are here concerned, but how can we tell when we understand them well enough? How often do we give, as our final conclusion in a research report, the equivalent of the following statement: "No further study of this problem is needed?" On the contrary, and understandably, we almost always recommend further study.

In this regard, we are, perhaps, not unlike our brethren in the law. Normally there is little or no incentive for them to complete the work on a case; the longer they can maintain the case in an open state, the longer they can continue to collect a retainer.

I realize that I am being a bit unfair to the lawyers and I hope, by the inference, that I am being notoriously unfair to my fellow laborers in this protective construction vineyard. But I think there is some truth to the suggestion. Researchers, by their natures, are curious people, and they realize that there is always more that can and, in their view, should be learned about a particular problem. But I wonder if we do not sometimes study problems beyond the point of useful return.

I am sure that you have all heard the story that is often used illustrate the difference between a mathematician and an engineer. A young man and a young woman are placed at opposite ends of a 20-foot long room, and are allowed to

approach each other, each of them moving, in succession, half the remaining distance to the other. The question then posed is "How many moves will be required before they meet?" The mathematician claims, quite correctly, that they will never meet, while the engineer, also quite correctly, observes that, for all practical purposes, they will meet in about 10 moves. We don't need to know all there is to be known about a problem before we can deal effectively with it.

I also recall an incident that occurred about twenty years ago. Some of you may remember when ASCE undertook a comprehensive study of the research needs of the profession. As chairman of the Structural Division Research Committee at that time, it fell my lot to coordinate this effort within that Division, and we requested from each of the technical committees of the Division a statement of the research needs in their areas of interest, including an estimated budget for the research work that they were proposing. In response to that request, one of the committees submitted a multi-million dollar proposal for further research on the shear behavior of reinforced concrete beams.

I still remember the observation that was made by one of the reviewers of that committee's proposal. It went something like this: So we mount a five-million dollar research study to improve our understanding of the behavior of reinforced concrete beams in shear, and what do we accomplish? If successful, we might improve the efficiency of the beam sections that we design by, at best, a few percent, and even that isn't certain. We would be better advised, he suggested, from the standpoint of the total building system, to throw in a few extra stirrups to cover the uncertainties that we know to exist in regard to the shear strength of reinforced concrete beams, and to spend most of that proposed research money studying better ways of incorporating the electro-mechanical system of a building within and around the structural frame.

Without debating here the merits of that reviewer's observation in that particular case, I think that his point has merit. We need to decide when one problem has been solved well enough, at least for the time being, and begin then to apply our resources to the solution of other then more pressing problems.

And now, one final question, which is not unrelated to the first two. Should we not be able to do a better job than we now do of coordinating the research work in the area of protective construction to try to make sure that problems get attention in proportion to their real importance, that no important problems are overlooked, that unnecessary duplication of research effort is minimized, and that the results of this research are speedily and systematically translated into procedures and guidelines that have practical application capability? There are, after all, a large number of organizations, some of which are governmental and others of which are civilian, that are involved in this total effort. And, as autonomous units, they are motivated, and constrained, by similar kinds of institutionally centered forces. As a consequence, it is not always clear that their collective efforts are as clearly focused on and directed toward a common objective as might be desired.

I raised much this same question when I spoke to the first of this symposium series two years ago. At that time, the pleas of a pair of Air Force Majors who were then stationed in West Germany were still fresh in my ears. They had problems to which they needed answers, and virtually their only sources of readily usable information were the Army's Manual TM 5-855-1, which was then about 17 years old, and the Air Force's Manual AFWL-TR-70-127, which was then about 12 years old, neither of which answered adequately the questions raised by those officers. A revised version of the Army manual has been recently issued, or is about to be issued. And that is good, but doesn't it seem reasonable, as a consequence of the very substantial amount of research that is conducted, that we ought to learn enough useful new information fast enough to justify sharing it with the practitioners of our art more than once every 15 or 20 years.

Once again I have exaggerated to make a point. Certainly, the results of the research that was conducted during those 20 years was not kept secret from those who needed it; the shelves full of reports that we all have in [illegible] offices attest to this. But timely, int[illegible]ative translations of these research [illegible] into conveniently usable practical gu[illegible]es are reasonably to be expected by field engineers. And I think that we may not have done quite as good a job in that regard as we probably could or should have done.

Given time, I might have been able to find a few more aspects of our protective construction research program about which to complain. But to do that would have been far more difficult than to ennumerate the large number of outstanding accomplishments of the many individuals and teams that are involved in this effort. Since time was not available today to attempt the latter, I have tried instead, by calling our attention to a few deficiencies, at least as perceived by me, to remind us that even a very good program can be improved. This program has been, and continues to be, a very effective one, and I am privileged to have had a small part in it. I am sure that you all join me in hoping that the day will soon come when we shall no longer have to worry about protective construction, but until that day arrives, let us continue to pursue with dedication the essential issues of this assembly. I hope that I may continue to have part in that effort.

# A BROADER PERSPECTIVE

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## INTRODUCTION

Thirty years ago, when many of our military facilities were built, there was no significant air threat, and we had the notion that nuclear firepower would substitute for conventional weaponry. Our adversaries viewed that position and then developed an integrated plan to gain strategic victories in Europe while maintaining a "no first use" pledge on nuclear weapons. Thus, the Warsaw Pact countries have pursued with great vigor the preparations they feel are necessary to conquer Western Europe in a matter of weeks with conventional military forces. The historical goal in that battle arena is to advance quickly, destroying infrastructure, military installations, and any enemy forces encountered.

With great hope in the policy of nuclear deterrence, the U.S. also decided to develop far more effective conventional tactical weapons. Even recently, Dr. George A. Keyworth, II, the President's Science Advisor, stated the administration's position that conventional weapons are a key to the transition away from dependence on those tactical nuclear weapons deployed in the field near potential battlegrounds. The thrust is therefore to use modern technologies to improve conventional weapon lethality, with much greater accuracy and damage potential.

These evolving conventional threats have created new problems in protective structure design. Unfortunately, the bulk of the supporting technology base is empirically founded and, in some cases, obviously outdated so that recent efforts have focused on improving this base to meet modern threats. Civil engineers, who previously were responsible primarily for maintenance and services, were given the responsibility for modernizing and rebuilding that technology base and now have new challenges in meeting both readiness and regulatory requirements. Most of the papers in this symposium report efforts in these directions. However, even though current research appears to be addressing immediate needs, perhaps this is the time to take a broader look at needs and goals, how will they change in the future, and what new directions we should be taking.

## THREATS FROM CONVENTIONAL WEAPONS

First, what do we perceive to be the current threats? That question can be answered in rather specific terms only by considering our opponents to have weapon technologies similar to ours. Traditionally, we think of military munitions such as projectiles, missiles, or bombs which deliver large amounts of energy on their targets either through impact and/or blast. Although there have been some enhancements in the performance of high explosives, the advancements in modern military weapons which overshadow all others are the tremendous improvements in delivery systems effectiveness and accuracy. Modern guidance techniques can place warheads on target with great precision, which has increased expected loadings on protective structures by orders of magnitudes and thus presents many new technical challenges.

When warheads were only expected to detonate at some distance from their target, loadings could be determined by choosing any equivalent charge weight and calculating overpressures, durations, and impulses by empirically derived methods. These idealizations and data bases, however, are insufficient for bombs directly impacting or detonating very close to their targets--within several charge radii, the blast environment includes intense shock waves, explosive products, and case fragments travelling at extreme velocity. This complex loading is difficult to idealize and there is very little experimental data for close-in detonations because most instrumentation simply will not survive the severe environment.

The loading is complex also for close-in ground shock even though fragment loading from the buried explosion is not as severe. When the buried charge detonates, the solid explosive is changed into an equal mass of gas at extremely high pressure which expands rapidly so that pressures at the explosive-soil interface can be hundreds of times greater than the strength of the soil, creating a zone of crushed material. If the charge detonates close enough to the structures, even the explosive products will contact the structure. Variability of soils and their properties makes it

difficult to predict accurately explosive coupling with buried structures and most instrumentation is also unable to survive this harsh environment.

The immediate problem then is to possess the capability to design or upgrade protective structures against modern threats for which expected loadings are poorly described. So far, the approach has been to attempt to improve the data base to include these more severe threats; however, the greater challenge is to expand our perceptions to the full spectrum of threats and anticipate how their future evolution will affect expected loadings and structural designs. And while we are trying to expand our perceptions, who will attempt to evaluate what new non-nuclear weaponry will appear from the SDI program to pose new threats to our present concepts of protective structural design?

## TARGETS

Although we think primarily of military facilities as the structures which require protection, we must also remember that the enemy intends to destroy infrastructure. This means that virtually any significant structure, military or civilian, is subject to attack. For the most part, the civilian sector is totally unprepared to meet such threats and therefore we have an additional long term goal in providing appropriate technology applicable to non-military facilities.

Protective military structures are designed to house vital functions or equipment of extreme value. Consequently, survivability takes precedence over appearance and the structures are usually massive with soil and concrete the main building materials. Protection needs are expressed by operational users in the form of requirements; the requirements are answered from the available technology base, or extension thereof, and the need is eventually met in the consequent design. Many of the papers to be presented in this symposium reflect efforts to extend our technology base for material properties and structural response to blast and impact loads. Granted, there is a pressing need to increase our technology base to meet current user requirements, but are we producing the technical advances which will significantly improve survivability in the long term? Unfortunately, technology developments in response to user requirements often are unacceptably slow. Retired General Bryce Poe II in The Engineering and Services Quarterly Journal recalled initiating items as a Captain in 1953 which were finally constructed when he was a Lieutenant General in 1974. Because the items were important to warfighting capabilities, he concluded that national security was at risk for more than 20 years. Can we afford similar time lags in the future? Is our national security at risk today for the same reasons?

Potential targets of a non-military nature come in a variety of descriptions and can include governmental, industrial, and civilian structures. These, unlike military facilities, have no well defined survivability requirements and are not designed to provide protection from weapon attack and are usually readily accessible. For example, United States embassies have historically been designed to reflect the openness and freedom of our society. Therefore, most of them do not use restricted access, heavy barricades, or special protective features to keep visitors at a distance. Consequently, they are very vulnerable to terrorist attack. More recently, we have seen some concern for protecting government buildings in Washington, D.C., as when trucks filled with sand were used to barricade the White House against possible terrorist attack. Especially vulnerable are industrial facilities such as power plants, petrochemical facilities, storage depots, etc., which may be spread out over large areas, leaving vital components exposed. Many terrorist attacks have been targeted against U.S. businesses abroad. Other civilian lifelines such as communication networks, pipelines, bridges, and such are completely unprotected, vulnerable to attack, and are undoubtedly already targeted in the event of conflict. Complete protection of all our facilities may be an impossible task, but our vision must be broad enough to develop technologies which will enhance the survivability of both our military and non-military against all opponents.

## OPPONENTS

While the Soviets have hundreds of bomber aircraft less than an hour's flight from NATO airbases, posing an evident threat, there are other opponents and threats for which we can only guess what kinds of loadings might be delivered.

Along with conventional troops, Soviet special purpose forces, SPETSNAZ, would be employed in wartime throughout Western Europe to covertly disrupt communications, destroy bridges, seize choke points, and to direct attacking aircraft to prime targets. These SPETSNAZ forces are weapons and demolition experts specially trained in infiltration tactics and sabotage methods using explosives, incendiaries, acids, and abrasives. Their realistic training includes accurate full-scale models of key targets. Their role is to operate from behind enemy lines and to attack major facilities and important weapon systems. The SPETSNAZ is suspected of having already participated in a number of covert operations, including assassinations. Their clandestine operations and expert use of explosives are tremendous threats to unprepared non-military as well as military facilities.

Since 1968, there have been more than 950 terrorist attacks against U.S. businesses, including more than 500 explosive bombings. Political extremists have exploited terrorism to attract world attention The target of a terrorist can be anything, but the more newsworthy the better. Alarmingly, terrorists have improved arsenals with modern weapons and explosives which can be placed in close proximity to unsuspecting targets. Car bombs, for example, have proved to be capable of awesome destruction and are very difficult to defend against.

Although terrorists activities began with civilian targets, recent attacks, such as the one on our Marine barracks in Lebanon, illustrate that military installations can also be targets. Unfortunately, some nations actually sponsor international terrorism and provide training, arms, sanctuary, and advice leading to an evermore sophisticated and unknown enemy with an unlimited array of targets. The terrorist issue is well recognized by the participants of this symposium who are involved with weapon storage design, but the technologies developed to combat terrorism against military targets must be transferred to those responsible for the protection of our civilian installations and personnel as well.

CURRENT ACTIVITIES

What are we doing to provide better defensive systems? From the papers to be presented in this symposium, several topics seem to stand out. As said, definition of loads from air blast, ground shock, impact, and combinations is a major concern, and the tremendous energy deposited on structures by close-in explosions is not easily characterized by previous idealizations and new methods are being sought. We are looking for better means of measuring the extreme loadings and better understanding of the coupling with structures. Another topic of immediate concern is structural response, in which there are at least three distinct areas of research: design, analysis, and testing. Several of the standard but now outdated design manuals have recently been revised or are under revision. But, even these revisions can only reflect the technology base as it currently exists and that is believed to be seriously lacking in many respects. More than a dozen papers at this symposium will discuss analytical techniques, ranging from simple approximations to attempts at very complex descriptions. A prevailing concern relates to better descriptions of material properties and failure mechanisms. We still have no clear-cut, standard, accepted methods for accurately describing the response of structures subjected to high amplitude short duration loads, although seemingly our understanding of dynamic materials properties is advancing. As in the past, the main emphasis in structural response research is testing and development of empirical relationships. Other papers in this conference range from testing new structural systems to revisiting World War II information. In some cases, scale model testing is being used to reduce test costs, and centrifuges are being evaluated as a method for testing geotechnical problems at very small scale. Centrifuge testing is viewed as an opportunity of overcoming difficulties in modeling soil because its strength is derived through gravitational forces, although there is some controversy over the validity of the technique. Many see centrifuges as the only way to test soil-structure interaction problems at small scale while others feel scaling gravity is totally unnecessary for blast studies; however, it is more important to remember that the centrifuge is simply a modeling tool and, like any other modeling technique, can only be employed usefully within the scientific understanding of the user. Other papers describe better instrumentation techniques and a few special problems.

The real question we must ask ourselves, however, is that even if we are 100 percent successful in every area of research being pursued, how much improvement will we gain in survivability? Are we making only incremental advancements at a time when major or revolutionary new concepts and results are required? What new directions should we be taking? Considering the evolving, expanding nature of the threats, and the payoffs we expect from our current research programs, will we be in a better position of survivability 25 years hence than we are today?

THE FUTURE

Conventional weapons systems will continue to improve, and pinpoint accuracy will require facilities designed for direct hits. We can surely expect that weapons will be smarter, with substantially improved projectile lethality, and overall will possess greatly enhanced power. Threats will not always come packaged as military bombs, and special forces and terrorists will possess sophisticated weaponry and will be apt to attack a broad array of targets.

What lies ahead in protective structures design? If current research is successful, we will be more able to describe loadings from nearby detonations; dynamic properties of concrete and soil will be better understood; and perhaps new and stronger materials will be used in construction. Without the development of novel design concepts and the introduction of radically different materials and construction techniques, however, we can expect only marginal improvements over current practice--that will not be satisfactory!

The key to long term survivability is to escape the trap of attempting to solve today's problems with yesterday's technology; rather, we have to begin to develop tomorrow's technology. This requires a thorough and careful analysis of future threats. I suggest the next symposium include invited speakers from the intelligence community to describe the capabilities that our adversaries might possess in the future. Furthermore, representatives from the user communities (both military and civilian) should be asked to express their anticipated needs. To stimulate effective technical thought in the researcher, it is essential to know as much as possible about the background of the problem, why it is important, what directions should be followed in developing possible solutions, and how will the results be utilized in practice.

The research community must strive for innovative concepts, applications, and techniques. New and different materials and construction methods are needed to match their full potential against very high intensity loads. We have depended for years on passive protective structures; perhaps active protective systems could be developed for civil engineering structures as they have been for

armored vehicles, missile silos, etc. Above all, we must maintain a broad perspective and look beyond narrowly defined problems and solutions by prescription; we must focus on long term goals and objectives which, with creative and innovative thinking, could neutralize opponents.

Those persons responsible for evaluating and funding research and development efforts should studiously avoid "more of the same" and "safe" research which can lead at best only to incremental advances. Instead, they should encourage and support truly innovative and revolutionary ideas; devote more resources to concept development and less to routine testings. Dare to be bold!

Once again, I urge you to think to the future--plan your next symposium with the future as your theme. In the meantime, concentrate all your efforts to maintain the broader perspective you will need to meet the survivability challenges of the decades ahead.

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# INTEGRATING BASIC RESEARCH IN THE INTERACTION OF NON-NUCLEAR MUNITIONS WITH STRUCTURES

LAWRENCE D. HOKANSON

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

Before I begin, I need to insure that I am up front with the audience on two points. First, all references to basic research will be in the context of basic research in civil engineering, not necessarily limited to the interaction of non-nuclear munitions with structures. The points to be made apply, for example, to phenomena associated with repeated loading of runway pavements as much as they apply to those phenomena associated with close-in blast loading of an aircraft shelter. Second, I realize the audience is composed of Air Force researchers, sister service researchers and the larger civilian research/academic community. I will no doubt step on the toes of members of one or more of the groups and I can only offer to buy a beer for the complainees....offer limited to the first ten and valid only during tax moratoria.

Later, some of the more critical gaps in our knowledge will be discussed. These track extremely well with many of the items identified by the Tri-Lab Five-Year Plan Working Group. There are many in this audience who will say, "but, we've already tried that." Many of the phenomena we are studying today have in fact been studied before, but it is not so much the subject matter that counts as it is the context in which an effort is tried. Consider that most, if not all, problems have been solved, and by some damn clever people. But lacking adequate basic knowledge, the solutions are forced explanations on a large scale phenomenological level of <u>how</u> an event takes place. The objective <u>is</u> normally predictive, the vehicle empirical and the technique correlative. One cannot dismiss the value of this type of engineering, and can even term it "research" in the engineering lexicon. The context in which I speak is one of science; one where understanding "how" is not enough. One must understand "why."

Several years ago, an accumulation of events made it apparent that airbase facilities supporting the finest aerospace craft known to man were not keeping pace in terms of capability, reliability and survivability. It was equally apparent that the strong technology base required for civil engineers to keep pace with the aerospace community did not exist; and worse, there was no comprehensive plan for its creation. Neither the level of research effort in civil engineering technology nor the level of funding was adequate to provide for more than stop gap developmental efforts. It was clear that the Air Force experience was not an anomaly. Research in civil engineering, and particularly civil engineering aspects of materials, had taken a back seat to aerospace research in industry as well as government. In a word, the discipline was stagnant. I can personally vouch for this stagnation. The tools available to do my job as a Chief of Engineering First Lieutenant supporting propeller driven RC-121s in Thailand varied little from the tools available 15 years later as a Base Civil Engineer Lieutenant Colonel supporting operations in a USAFE dominated by highly sophisticated F-15s and F-16s. As another example, while serving as an advisor in Saudi Arabia, I was frankly embarrassed at the crude state-of-the-art available for use when the Royal Saudi Air Force requested an assessment of hardened facility designs for other than NATO criteria. Answers did not, and to a large degree, do not exist.

Many looked to the up and away portion of the Air Force for solutions. What they found was the finest institutionalized Research, Development, Test and Evaluation (RDT and E) capability in the world. Even with considerably less funding and resources, the aerospace research community was

technologically outstripping its iron curtain counterparts on a daily basis. The fountainhead of that system was and is an advanced technology base underpinned by the basic research capability that exists within the Air Force research community; a capability in which civil engineering neither provided input nor shared output.

The first step in bringing this capability to bear on civil engineering problems was creation of a Civil Engineering Technology program within the office responsible for single point management of the total Air Force basic research program, the Air Force Office of Scientific Research (AFOSR). Two of the limited positions belonging to the Air Force Director of Engineering and Services were transferred to AFOSR to initiate the Air Force's 6.1 Civil Engineering Technology research program. Understanding of this program requires an understanding and appreciation of the concept of 6.1, basic research. It is defined in AFR 80-1 in terms of increasing KNOWLEDGE and UNDERSTANDING, LONG-TERM national security needs and FUNDAMENTAL knowledge. This contrasts sharply with 6.2 plus or developmental efforts, which are defined in terms of APPLIED research, BREAD BOARDED experiments and SPECIFIC military problems. More to the point, basic research is phenomena oriented, not to be confused with large or macro scale phenomenology. Phenomena orientation deals with science and the art of observation, explanation and verification. It deals with "why" and not "how," with the understanding that the knowledge inherent in "why" will allow one to control, not merely predict. The creation of costly data points in hyperspace, in the vain hope that given enough data an answer will fall out, becomes unnecessary. Bluntly, if the question of "why" is answered, one need not dig through the pony poo in fond hopes that a pony resides at the bottom.

My tenure at AFOSR has brought me face to face with three fundamental issues: first, what constitutes good science?; second, what topics should be pursued?; and third, who should do the pursuing? The answers are somewhat intertwined, but it may help to give examples of good science and not so good science. My favorite exampl of good science predates my arrival at AFOSR. It shows that development of a moisture resistant polymer concrete resulted from a scientific understanding of polymer chemistry, explaining why moisture impacts the strength performance of the material. By defeating the weakening mechanism, up to twice as much water can be tolerated in the aggregate. Alas, for every example of success there are ten examples of good research opportunities that fall short. Determination of the shear modulus of soil by measuring electrical conductivity is but one example of many. The effort correctly identified soil conductivity as a non-mechanical response, but failed to provide the required "why." From an engineering standpoint, the correlative technique of relating the conductivity response to a well known measurement of mechanical response is meaningful, but basic research would demand an explanation of "why" the soil responds as it does when interrogated. Far too many times the researcher takes the easy route, answers the "how" and forsakes the "why."

Who should conduct basic research? This question focuses on the understanding scientists have of engineers and vice versa. The story of what scientists define as a "shame" is enlightening. If a bus full of engineers runs over a cliff and there is one empty seat, that is a shame. Engineers are just as complimentary. They ask, "What difference is there between a dead opossum in the road and a dead scientist in the road?" Answer: there are skid marks in front of the opossum. The researcher able to tackle civil engineering problems is a unique and scarce breed. He is generally an engineer who has carefully traced the roots of engineering back into pure sciences such as chemistry, physics, or math, and in so doing, trained himself as a scientist. Occasionally he is a scientist who has become interested in an engineering problem. The most productive is the engineer who teams with engineers in other disciplines and with appropriate scientists. The world is rapidly becoming too complex for loners; interdisciplinary approaches are a necessary reality.

What topics should be pursued? Where military engineers are involved, topics must be tied to weapons requirements. And, not just protection from hostile weapons, but unique support of friendly weapons systems. Without the weapon, the military civil engineer is little different than a municipal engineer. The weapon is the raison d'etre. Weapons needs must drive research issues. However, in the world of basic research one must be extremely careful not to chase requirements so persistently that he loses sight of opportunity. Opportunity is every bit as important as requirement. The recycling of ideas and painful evolutionary improvement in

several areas with which we in the Air Force are familiar serve as classic examples. Again and again we redoubled our efforts in the vain hopes of success, ignorant that the basic technology required for acceptable advancement simply didn't exist. Clearly lack of advancement was not due to a lack of personal dedication and sacrifice. It was because we persistently ignored the basic research required to develop an acceptable technological base. The point, however, is that money and resources alone cannot solve a problem. There must exist opportunity in the form of individual principal investigators, organizations or institutions who have demonstrated knowledge and insight into phenomena within a topical area. Incidentally, insight is not a commodity which can be placed in a statement of work; its possession by a researcher is mandatory to establish that opportunity exists. The good project officer or program manager must carefully balance requirement against opportunity and maximize the output of his long term investment dollars. The good commander creates the environment in which this process can take place.

Additional thoughts regarding the selection of research projects center on the visualization of the research and development process shown in figure 1. One must realize that basic research is pervasive throughout the research and development process. One of my largest disappointments is the repeated questioning I receive on how I plan to transition 6.1 to 6.2 efforts. There is no single answer. Basic research, 6.1, often feeds other 6.1 which in turn feeds the knowledge pool with no direct connection to development. It is always nice to be able to demonstrate 6.1 that goes directly into field application, but by charter, 6.1 must look 5, 10, 15 or 20 years into the future. With the total Air Force 6.1 budget being only a little more than 200 million dollars a year, one cannot afford to blunder into specific applications. A final thought, perhaps the best way to identify fruitful research topics is to ask what it is we don't do well. If the answer can be traced back to what phenomenon it is we don't understand, we may be on the road to identifying science or 6.1 issues.

Now to answer the question you have all been too polite to ask: just what is happening in the Civil Engineering Technology basic research program? For Air Force members of the audience, this is a progress report on how we are fairing in our effort to get our foot in the door and begin sharing the top end of the full spectrum Air Force Systems Command (AFSC) Research, Development, Testing and Analysis (RDT and A) system. For the research community, it confirms the opportunities available for you to practice basic research, to get into the "why" game in a funding scene dominated by short fuse "how" demands. For those in sister services, it may surprise you that AFOSR spends more on civil engineering research than the Army Research Office and Office of Naval Research combined.

Currently we are operating with one program manager, although we are interviewing for a civilian to provide more stability in the geotechnical area. Funding has continued to increase, reflecting an emphasis on research by the current administration and approval of civil engineering oriented science by the management at AFOSR. Next year we are programmed for 2.7 million dollars in the civil engineering technology area, and that does not include AFOSR managed 6.1 funds at Air Force laboratories or 6.1 funds being spent in support of engineering and services in AFOSR programs other than the Civil Engineering Technology program. Our financial health received a big boost last week when an an FY 87 initiative was approved for research in nonmetallic structural materials. Up to 1.5 million dollars a year will be spent on hydraulic cement matrix concretes. Still, AFOSR is a highly competitive, scientific institution; programs are in open competition on a continuing basis. There are two measures of success and both must be strong for survival. First, work must be "relevant" to Air Force requirements; secondly, and of paramount importance, work must clearly qualify as good science. This is not simple when civil engineering is in head to head competition with scientific efforts in basic sciences such as chemistry, physics, and mathematics. The civil engineering program, almost as a result of its name, is in the unenviable position of having to continually demonstrate that it seeks and is built upon good science, a task that, in my perception, the "sciences" are often able to duck.

Perhaps a further measure of success, or at least progress, is the state of the research community. Twenty five percent of the presentations in this symposium are direct results of AFOSR funded research. As with most statistics, this is deceiving. The concept of basic science is not well understood nor well supported by the community. While the program is well supported in terms of

the number of unsolicited proposals (the fuel for all AFOSR programs) received, I am forced to say that, from a scientific viewpoint, these proposals are impoverished. As a result, the program has perhaps one of the largest "iterative" schemes found in AFOSR. Currently there are some 60 researchers who have active proposals or preproposals in the iterative process. Unfortunately, only a small percentage of these researchers will turn the corner to identify and pursue relevant "science" issues. The Director of Aerospace Sciences, the man who controls the size of the Civil Engineering Technology basic research budget, is adamant in his belief that funding must be based upon opportunity. If a surplus of scientific opportunity does not exist, there is no reason to either stabilize or a grow a program.

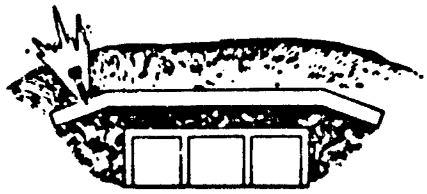
The Civil Engineering Technology program is currently based on 11 separate work efforts. These include the "scientific" aspects of constitutive models for soil, in situ soil behavior, soil stabilization, soil liquefaction, transient soil properties, rock mechanics, structural response, fracture characteristics of brittle geotechnical materials, concrete stress-strain modelling, expedient facilities, and structure-media interaction. The ultimate support of projects in each area is predominantly dependent on the availability of opportunities. I also have a hit list of my favorite issues. Is there really such a thing as strain softening? Are we forever doomed to measure in situ soil properties by shoving on one side, then running around to measure the movement on the other side? What are the causative factors in concrete strain rate dependence? Will we always naively accept the solid mechanists view of geomaterials as aberrations of metals? Are yield surfaces really appropriate for particulate materials?

While I'm not religious enough to pass a collection plate, I do want to make a plea. As engineers (and maybe a few scientists), you are the key to developing a technology base for civil engineers, a technology base required to bring us up to the technological state of the aerospace community. To participate, you must be able to discriminate between engineering and science. Engineering is an honorable calling, but it deals with finding an acceptable solution, often for an existing problem and generally using existing knowledge. It does not answer "why"; it does not adequately support development of a technology base. You must use your experience to identify those gaps in knowledge which prevent us from doing a better job, pursue their definitions until a scientific issue has been identified, and work with the scientific community until the knowledge you need is generated. Frequently you must do this from within a culture that wants only answers to immediate problems; a culture that will seldom reward you for being thorough in following-up on the "whys" of a phenomenon. Your only rewards may be internal, and that may not be reward enough for the complacent.

This week, you should be extremely critical of the symposium presentations which you attend. Be candid in discussing work with your colleagues. Ask the hard questions. Find out if your colleagues know and can accept the assumptions upon which their work is based. See if they have identified or pursued a scientific issue. You may find some surprising answers, and those answers may impact your view of your own work.

Thank you, and have a super week.

AFOSR



SECOND SYMPOSIUM ON THE INTERACTION

OF NON-NUCLEAR MUNITIONS WITH STRUCTURES

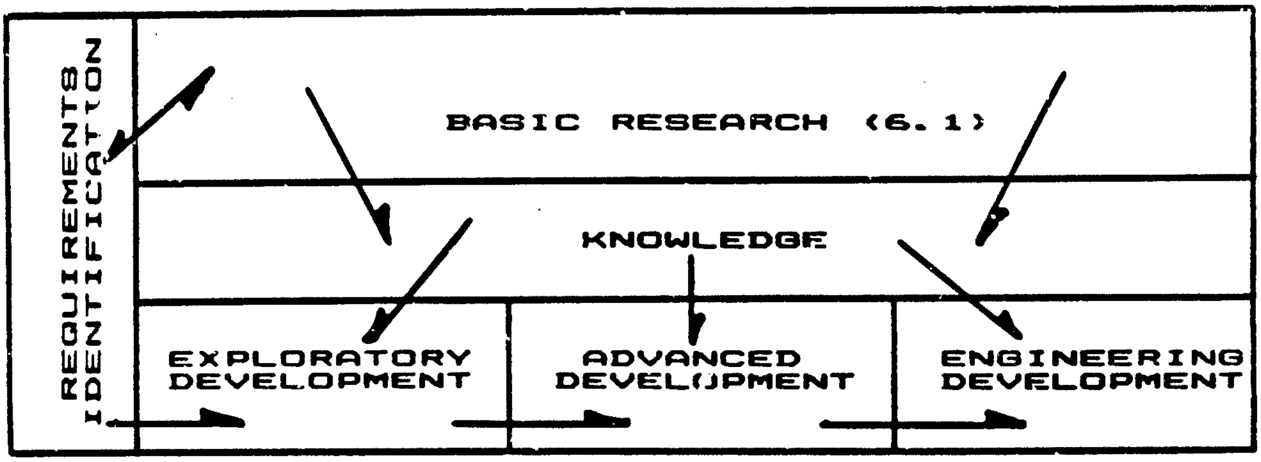



FIGURE 1

# THE CORPS OF ENGINEERS WEAPON EFFECTS PROGRAM

James Choromokos, Jr.

Director, Research and Development

US Army Corps of Engineers

Introduction: When Paul Thompson called last September and asked me to provide a "kickoff" presentation to this illustrious group of scientists and engineers, I accepted without a moment of hesitation. I did ask Paul what I should talk about, and Paul, in his infinite wisdom said, "Talk about your past experience, your present job, and the cooperation among the other military services and foreign countries." This would appear to be a simple task, but to tell you the truth, I have agonized more on this talk than any other presentation I've given, including presentations to Congress.

Background: My involvement with weapon effects dates back to the mid-fifties, almost 30 years ago, with the Air Force Research and Development Command (ARDC), now called Air Force Systems Command, with the TITAN, MINUTEMAN, and NORAD COC. I was fortunate to be assigned to the Defense Atomic Support Agency, now Defense Nuclear Agency (DNA), in the early sixties, during the last atmospheric testing in the Pacific and at Nevada Test Site. With the Limited Nuclear Test Ban Treaty in 1963 which restricted nuclear atmospheric testing, I became heavily involved with a large number of nonnuclear high explosive (HE) tests to simulate the effects of nuclear weapons, to include airblast and ground shock on structures and equipment.

Simulation Tests Experience: Some of the interesting simulation tests were the first 500 ton (or 1 million pound) HE explosion in Canada in 1964 called OPERATION SNOWBALL, followed by three 500 ton shots in Hawaii in 1965 called OPERATION SAILOR HAT, a variety of (phenomenology) events using TNT and detonable gas balloon shots during OPERATION DISTANT PLAIN in 1966 and 1967, and in 1972, I was the Technical Director for the first 500 ton HE test in the US at Grand Junction, Colorado, called MIXED COMPANY. All of those tests involved participation among the three military services and foreign countries, in particular, the United Kingdom (UK), Canada and the Federal Republic of Germany (FRG).

Conventional Munitions Experience: During my fun time of blowing things up, I was also involved with the effect of conventional munitions on military structures. I was involved with the Air Force's CONCRETE SKY test series on the TAB VEE aircraft shelters,(or the 1st generation shselter) a test of Iranian aircraft shelters against rockets, fuel air explosives (FAE) on structures, bomb damage repair of runways, and the aircraft shelter complex test series at Eglin AFB, Florida. Also, I was and am still working on camouflage and dummy structures.

USAFE Experience: While I was Director of Construction for USAFE from 1973 to 1976, I directed the design and construction of the third generation shelter and door and participated in the successful HE test of the door in 1976.

IIT Experience: After retiring from the Air Force in 1976, I taught structural engineering and construction management in the Civil Engineering Department at IIT for three years until I was offered a job I couldn't refuse.

DRD Experience: My present position is Director of Research and Development for the US Army Corps of Engineers. As you may know, the Corps R&D Program involves both Civil Works and Military R&D to include reimbursable work. Under my direction there are eight Corps labs employing over 2600 people with a total R&D funding of almost $250 million. Of that $250 million, approximately $35 million is being spent for nuclear, nonnuclear, and camouflage R&D thru our Army and reimbursable R&D program. So you can see, I'm still involved with weapon effects and allied work.

Corps R&D: From my preceding discussion, you can see that I have had a variety of interesting and exciting experiences, assignments, and duties related to weapon effects. What I have found interesting in my present job is the synergistic effects that have taken place in the nuclear and nonnuclear weapon effects R&D and vice versa. What I would like to do for the rest of my time is review with you some recently completed and present R&D in the Corps labs related to weapon effects.

Recently Completed Work: During the past 5 years, the Corps thru its labs, particularly the Waterways Experiment Station (WES), has been involved in a number of high explosive shots in testing a wide variety of structures and components. Most of this work has been in support of, or in cooperation with DNA and the Air Force.

We have recently participated in several nuclear simulation experiments with DNA's--DISTANT RUNNER and MILL RACE in 1981, and DIRECT COURSE in 1983. In the 100-ton DISTANT RUNNER event, third generation aircraft shelters were exposed to the effects of external and internal explosive detonations. From these tests we were able to assess the capability of the shelters to protect aircraft, munitions, and personnel from both a simulated nuclear airblast and a conventional HE detonated internally.

To help establish the vulnerability of industrial structures to nuclear attack, we tested a steel frame structure in the 600-ton MILL RACE event in 1981. This same structure after new siding was installed was retested in the 600-ton DIRECT COURSE event last year. From these tests we determined airblast loading and structural response of the building and drag coefficients for various structural members. We have used these data to verify our vulnerability prediction methods. Also tested in the DIRECT COURSE event was a reinforced concrete blast shelter entryway complete with blast doors--a 3-inch thick reinforced concrete door, and a commercially available fire-rated door reinforced with wide-flange beams and steel plates. The concrete door, survived with only slight deformation, while the modified commercial door was completely destroyed. The success of this relatively simple concrete blast door has led to the development of similar blast door designs to resist very high close-in pressures, including fragment loading from conventional weapons. This follow-on work is being done at WES and funded by the Air Force Engineering and Services Lab.

We assisted various sponsors in testing different structural concepts to gather data on structure loading and response for analysis and validation of structure designs. Some examples include ...

... Flat-roof, shallow-buried structures. Through a series of scale-model tests in a simulated nuclear overpressure, we determined that such structures were an order of magnitude harder than formerly predicted (2,000 to 3,000 psi instead of 200 to 300 psi). These data have resulted in related research, funded by the Air Force Engineering and Services Lab, into the vulnerability of buried structures to earth penetrating conventional bombs. The Ground Launch Cruise Missle (GLCM) shelter is an earth mounded, three-tunnel concrete structure with a burster slab. Extensive tests on both the burster layer and structural models have been conducted by the Armament Lab at Eglin and at WES to gather data which were used to modify and verify the burster layer configuration and structural design.

Our test and analyis efforts were instrumental in the final selection and design of structural and shock isolation systems for the new hardened war headquarters for SHAPE. We evaluated the hardness of various U.S. and NATO communication cables and conducted in-place vibration tests of the Project 85 (P-85) structures with a 1 KIP shaker, and a 50 KIP shaker to verify the as-built conditions. This was a cooperative effort between the Air Force Engineering and Services Lab, WES and DNA.

For the Federal Emergency Management Agency (FEMA), we did design calculations using results from the shallow-buried structures research, and tested scale models of the 100-man keyworker Civil Defense Blast Shelter to validate and optimize the design. The final design will be verified in a full-scale structure experiment in the MINOR SCALE HE test at White Sands this June. MINOR SCALE will simulate an 8-kiloton nuclear detonation. And we proof-tested a full-scale 18-man galvanized steel keyworker shelter which survived a simulated 50 psi, 1-megaton detonation with no damage.
Finally, we have field tested and evaluated numerous field fortification designs such as an earth-covered polyurethane foam arch shelter, for surviving near misses from artillery and mortar rounds. Some other designs tested were a frame-fabric shelter, and a tubular sandbag bunker.

We have evaluated available engineering materials for defeating the fragmentation effects from exploding munitions. Some materials evaluated include concrete, brick veneer, and fabric. New candidate materials for field fortifications are continually being evaluated. To provide protective shielding for buried $C^3$ structures, we have tested and evaluated rock-rubble boulder screens for defeating or degrading the penetration capability of air-delivered weapons. This work has led to the development of analytical models and design guides for the use of boulder screens as protective systems against penetrating weapons. This work has been a cooperative effort with the Air Force Engineering and Services Lab, the Navy at China Lake, and the FRG.

We evaluated the effectiveness of military explosives and linear shaped charges to quickly prepare openings in walls for assault building entry. Walls tested were of masonry and reinforced concrete up to 12 inches thick.

To gather data on the effects of fuel-air explosives against urban structures, we built a structural frame with replaceable wall panels at Fort Polk, Louisiana, to allow testing of different European wall sections. Data from

these tests have been used to develop loading functions and a technique for predicting damage levels to masonry structures from different size rounds at any range.

A spin-off from our weapon effects R&D is the work we have done on barrier creation. We have conducted numerous tests on the use of conventional and nuclear weapons to breach concrete and earth dams. Based on our analysis rockfill dams are less vulnerable than concrete dams. We also have procedures for predicting the flooding caused as dams are breached. We have successfully tested and demonstrated the use of liquid explosives in buried pipes to create impassible antiarmor ditches. The pipes can be pre-emplaced, filled with liquid explosives when needed, and then detonated as the tactical situation demands. The M1 Abrams and LEOPARD 2 tanks were immobilized during joint tests in Germany with the Federal Republic of Germany last summer.

Another project with Germany was the creation of mountainside roadway barriers from 500-kg charges placed in preconstructed shafts in roads. Tests relating crater dimensions to shot design and shot environment were used to develop a method for predicting crater size and shape in rock.

We have provided test and instrumentation support to the Air Force on the MX/Peacekeeper program. Scaled experiments were conducted at White Sands to simulate the blast and ejecta/debris effects from an explosion of a Peacekeeper missile within a Minuteman silo. Tests at Fort Polk on silo components were used to obtain data to design the full-scale silo structure to house the small missile. And WES also fabricated and instrumented the steel work for two one-third scale silos for tests at Yuma, Arizona.

Current Work: With that brief rundown on our recently completed work, I would now like to tell you about some of the exiciting things we are presently doing.

We have teamed up with the Chemical Research and Development Center to develop methods to upgrade existing hardened structures for chemical-biological protection. Two full-scale shelters--a fabric/frame shelter and a concrete arch shelter--are being tested and evaluated to determine if they are suitable and safe for use against chemical agents and weapons. These same two shelter designs--the fabric/frame, and the concrete arch--will be tested in DNA's MINOR SCALE event in June 1985 to verify design loading criteria and to determine if the shelter equipment will continue to operate when subjected to airblast and ground shock. Also to be tested in the MINOR SCALE event is a full-scale 100-man keyworker blast shelter complete with blast door, operational equipment, and instrumented mannequins.

Other shelter designs being tested in the MINOR SCALE event include a composite shelter which is a combination of two designs--one by the Norwegian Government and one by the Swedish Government. One half of the shelter is the Norwegian design and the other half is the Swedish design. Both a prototype and a 1/4-scale model will be fielded. The prototype shelter is for the Norwegian and Swedish governments to proof test their designs against the blast effects of a simulated 8-kiloton nuclear weapon. The 1/4-scale model shelter is for FEMA to evaluate the yield effects of a 512-kiloton simulation on Civil Defense type shelters.

This Fall, WES will assist the Air Force Engineering and Services Lab in full-scale hardened structure tests to evaluate procedures for the design of semi-hardened structures to resist NATO threats. This test will provide data on the response of reinforced concrete semi-hardened facilities, blast doors, blast valves, and other structural components to NATO threat criteria. Two WES blast door and several commercial blast door designs will be include in the test.

Since scale models are frequently used in both conventional and nuclear weapons effects testing, we are investigating scaling effects in shallow-buried structure tests. Preliminary results from tests on a structure twice the size of the scale-models tested previously, indicate little or no scale effects.

We recently developed a sand grid system for expedient construction of roadways over sandy soils. We are currently evaluating them for use as revetments for expedient field fortifications. Three-feet-thick sand-grid revetments constructed as high as 10 feet have been shown to be effective against small arms fire, 105mm flechette rounds, and 155mm HE rounds as close as 5 feet.

We are conducting tests to define blast pressure buildup inside small fighting positions from near misses by artillery and mortar rounds. With the firing ports open, blast pressures inside the position are sufficient to cause severe or lethal injury. But a ballistic nylon curtain placed over the firing ports and entrance to the position reduces the inside blast pressure to levels that would cause only minor injury.

This year we have initiated research to decrease the vulnerability of buildings against terrorist attack. Terrorist attack of buildings is becoming more frequent, sophisticated, damaging, and lethal. Many buildings are of conventional construction and are not designed to withstand the weapon effects resulting from an attack. Our work will focus on finding ways of upgrading existing facilities and designing new ones to enhance their survivability.

We are developing Electro-Magnetic PULSE (EMP) protection criteria for hardening Command, Control and Communications ($C^3$) facilities. Our initial work began sometime ago with the SAFEGUARD ABM system. Current studies include solutions for deteriorated gaskets, use of laser welding and application of arc-sprayed metals for EMP shields, and assessment of EMP hardness of power systems.

We have a Bi-Axial shock test machine which we commonly call a "shake table" that is used to determine the vulnerability of equipment to vibration and simulated ground motions. It has a 12-foot square platform for testing equipment in individually controlled horizontal and vertical directions simultaneously over a broad frequency range of 1 to 200 Hz, producing accelerations of up to 40g's vertically and 20g's horizontally. The facility is located at our Construction Engineering Research Laboratory.

Our participation in the hard silo component test program in support of the Small Missile System for the Air Force's Ballistic Missile Office (BMO) is continuing this year. Approximately 35 component and silo HE tests are being conducted at two sites — one at Ft. Polk, and the other at Yuma, Arizona. Information from these tests is being used to validate structural designs for the large scale silo superhardening technology program.

Toward development of new concepts for clearing mines with explosives, we have tested the M58 and British Giant Viper munition to establish the effects and cause of the air blast skip zone characteristic of line charges. At the present time, we are evaluating liquid and slurry explosives, fuel air systems, and new deployment techniques such as parallel line charges, pumpable explosive fillers in plastic tubes, elevated charges, and linear fuel-air clouds.

With the cooperation of the Air Force Armament Lab, we are developing new, basic weapons effects data for modern penetrating bombs to upgrade hardened structure design requirements. Data include penetration, ground shock, and damage radii measurements from static and live-dropped bombs, and blast penetration calculations for hard or buried fortifications.

In a study for BMO, we are proportioning new concrete mixtures using silica fume and recently developed admixtures to obtain unconfined compressive strengths of 14,000 psi and higher. A 2.4 million pound servo-hydraulic loader is being used along with a 200,000 psi triaxial test chamber to determine the strength and deformation characteristics of this material under high confining stresses. Failure and deformation data derived from these tests will be used by the Air Force in the analysis and design of strategic structures.

In support of tests by the Air Force Tactical Warfare Center, we evaluated the feasibility of using ground penetrating radar techniques for mapping the penetration path and determining the terminal location of air dropped bombs penetrating a runway. We found that mapping the penetration paths was not feasible because the tunnels left by the bombs collapsed immediately after passage of the projectile. But our initial assessment of the test data indicates that ground penetrating radar will accurately locate the subsurface position of buried bombs.

My final example of Corps R&D concerns survivability of fixed high asset installations from air attack using camouflage, concealment, and deception techniques. In January of this year we published an Air Base Camouflage Manual for the Air Base Survivability Office at Eglin AFB. We are currently participating in two major camouflage demonstration projects in cooperation with the Air Force—one is a joint US and UK experiment at Lakenheath Air Base in the United Kingdom. And the other is a US Air Force Experiment at Spangdahlem Air Base in Germany. This camouflage experiment should be effective against visual and thermal infrared sensors, and will include false operating surfaces, decoy aircraft shelters, and decoy bomb damage as well as the more conventional tone down and shape disruption techniques.

In conclusion, I have presented a brief overview of some of the recent past and current weapons effects research in the Corps. In reviewing this work with you, I find it particularly gratifying to note the excellent cooperation that has been demonstrated between the Corps labs, the Air Force Tri-Labs (the Engineering and Services Lab, the Armament Lab, and the Weapons Lab) the Navy and our foreign partners. I believe we have achieved a high degree of synergism between nuclear and nonnuclear weapon effects through our many and diversified cooperative efforts. Indeed, this symposium is an excellent example of the synerism resulting from the cooperative efforts of those of us in the weapon effects community.

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